the standard in safety

FPRF/UL Smoke Characterization Project

Characterizing Materials During Smoldering and Flaming Fires

Paul E. Patty, P.E.
Sr. Research Engineer
Underwriters Laboratories, Inc.
tel: 847-664-2752
paul.e.patty@us.ul.com

FPRF Technical Panel

David Albert, InnovAlarm

Thomas Cleary, National Institute of Standards and Technology

Kenneth Dungan, PLC Foundation

Jackie Gibbs, Marietta Fire and Emergency Services

Daniel Gottuk, Hughes Associates, Inc.

Morgan Hurley, Society of Fire Protection Engineers

Arthur Lee, U.S. Consumer Product Safety Commission

James Milke, University of Maryland

Robert Polk, National Association of State Fire Marshals

Lee Richardson, NFPA

Sponsors

Underwriters Laboratories Inc.
BRK Brands/First Alert
Centers for Disease Control
GE Security
Honeywell Life Safety
Invensys Climate Controls
InnovAlarm
Kidde Safety
National Electrical Manufacturers Association
PLC Foundation
SFPE Foundation
Siemens Building Technologies

Objective and Scope

Develop smoke characterization analytical test protocol using flaming and non-flaming modes of combustion.

Objective and Scope

Develop smoke particle size distribution data and smoke profiles in the UL smoke detector room for materials found in residential settings for both flaming and non-flaming modes of combustion.

Objective and Scope

Provide data and analysis to the alarm/detector/additive industries for several possible initiatives:

A) **Develop recommendations to the current residential smoke detector standard (ANSI/UL 217).**

B) **Provide data for the development of new smoke sensing technology.**

C) **Provide data to facilitate new smoke suppression technologies and improved end products.**

Materials

Survey materials and products in contemporary residential settings

Select materials for the research investigation:

- **Presence in residential settings**
- **Chemistry**
- **UL 217 specifications**

Samples

UL 217 Materials

- Heptane/Toluene
- Douglas Fir
- Newspaper
- Ponderosa Pine
- Cotton wick

Other Materials

- Bread
- Cooking oil
- Lard
- Heptane
- HDPE
- Cotton batting
- Cotton sheet
- Cotton/Poly sheet
- Polyester microfiber sheet
- Rayon sheet
- PU foam
- Polyester pillow stuffing

Products

- Pillow
- Mattress
- Coffee maker
- Nylon carpet
- Polyester carpet
- PVC wire
- Polyisocyanurate foam

Sample Characterization

Weight analysis – area or volume density

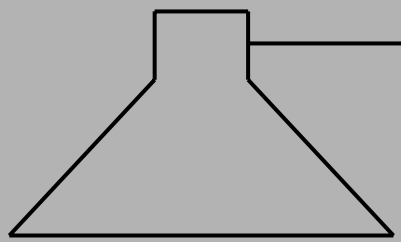
Chemistry – Nicolet Nexus 470 FTIR

Thermal Degradation – TA Instruments Q500 TGA

Photograph

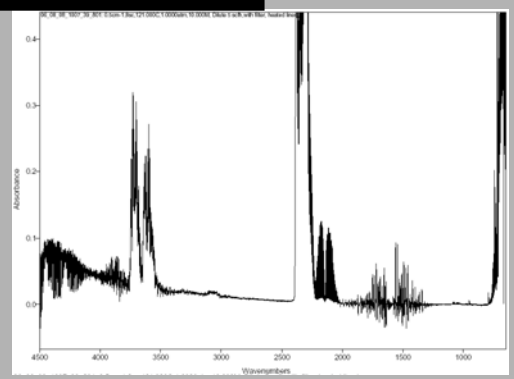
Sampling Method

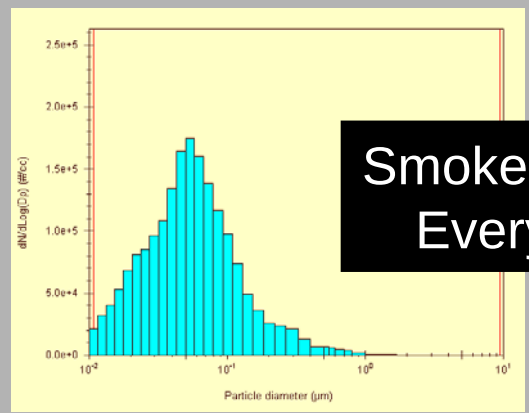
Calorimeter



N_2 dilution

FTIR
Every 15 s

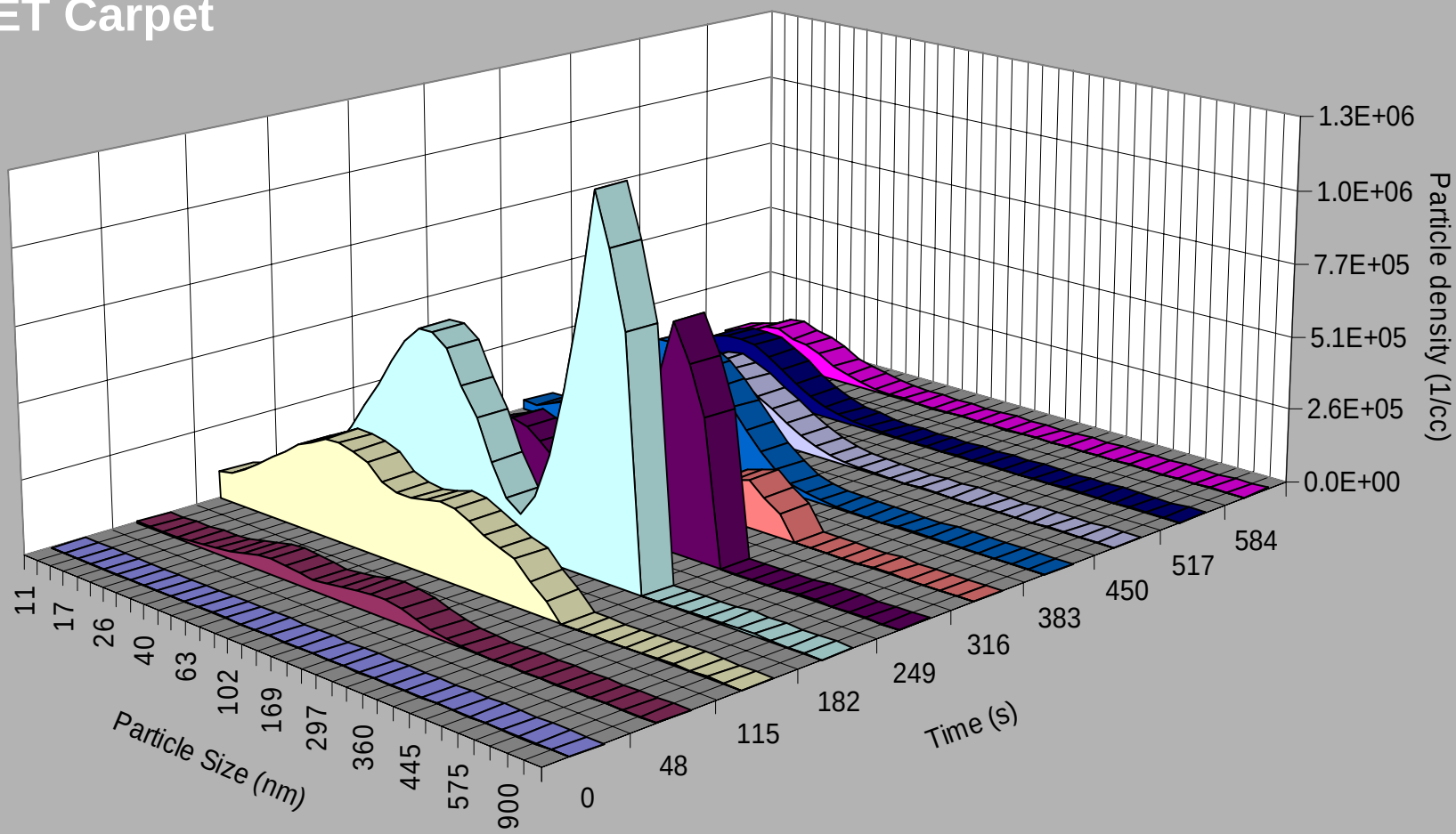




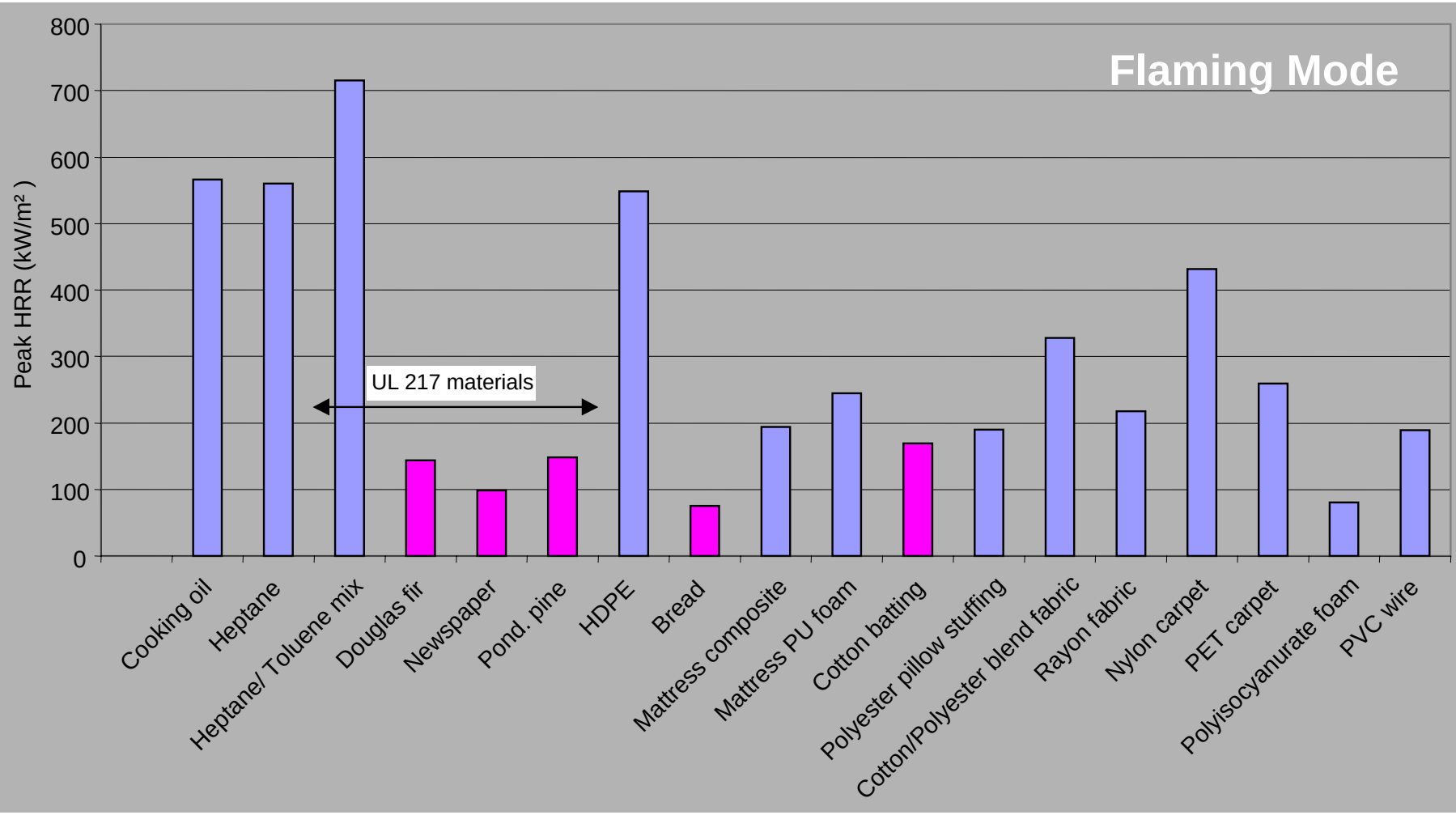
Smoke Particle
Every 67 s

Smoke Particle Analyzer Data

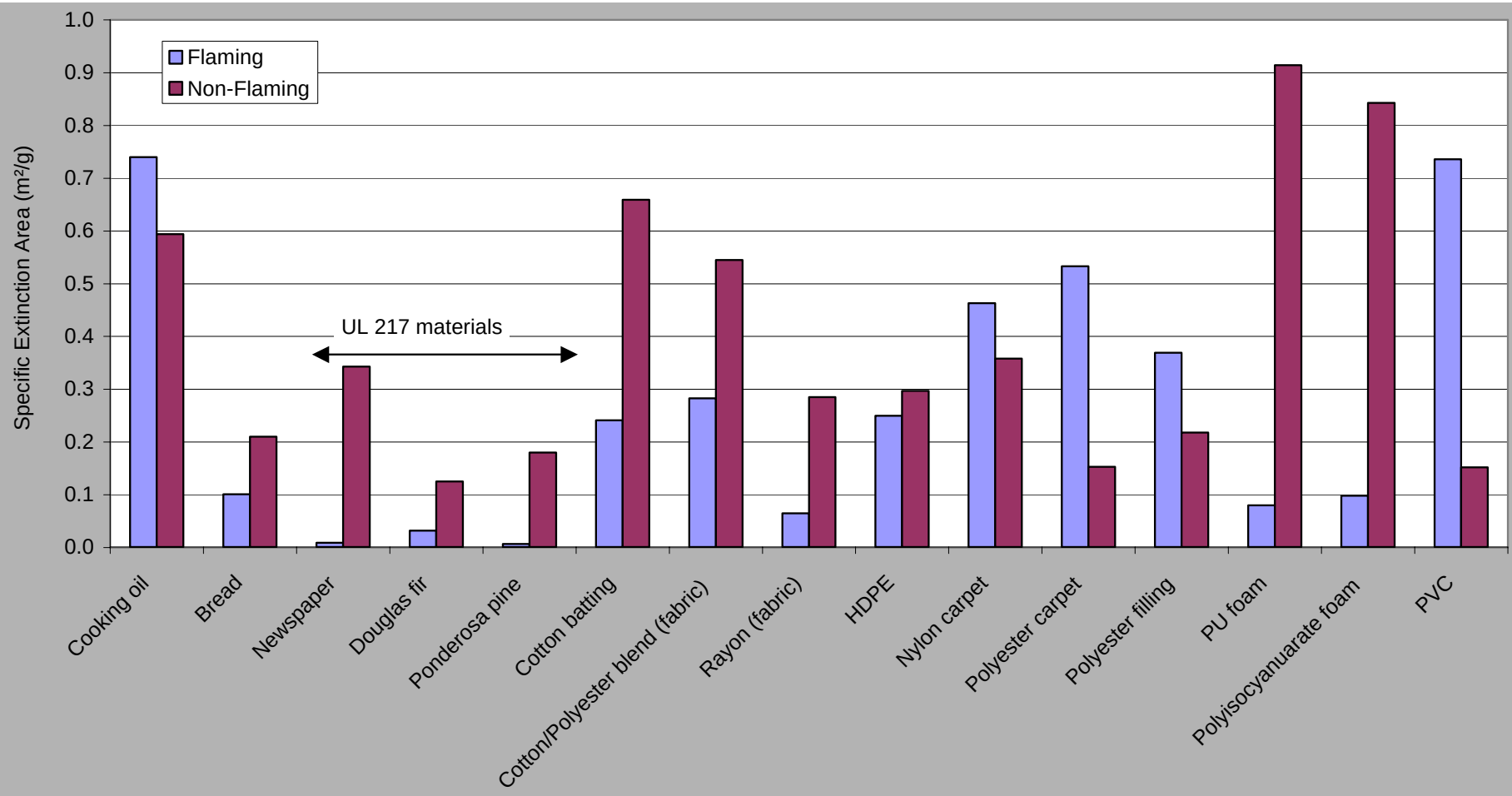
PET Carpet



Key Findings - Influence of Material Chemistry



Key Findings - Mode of Combustion

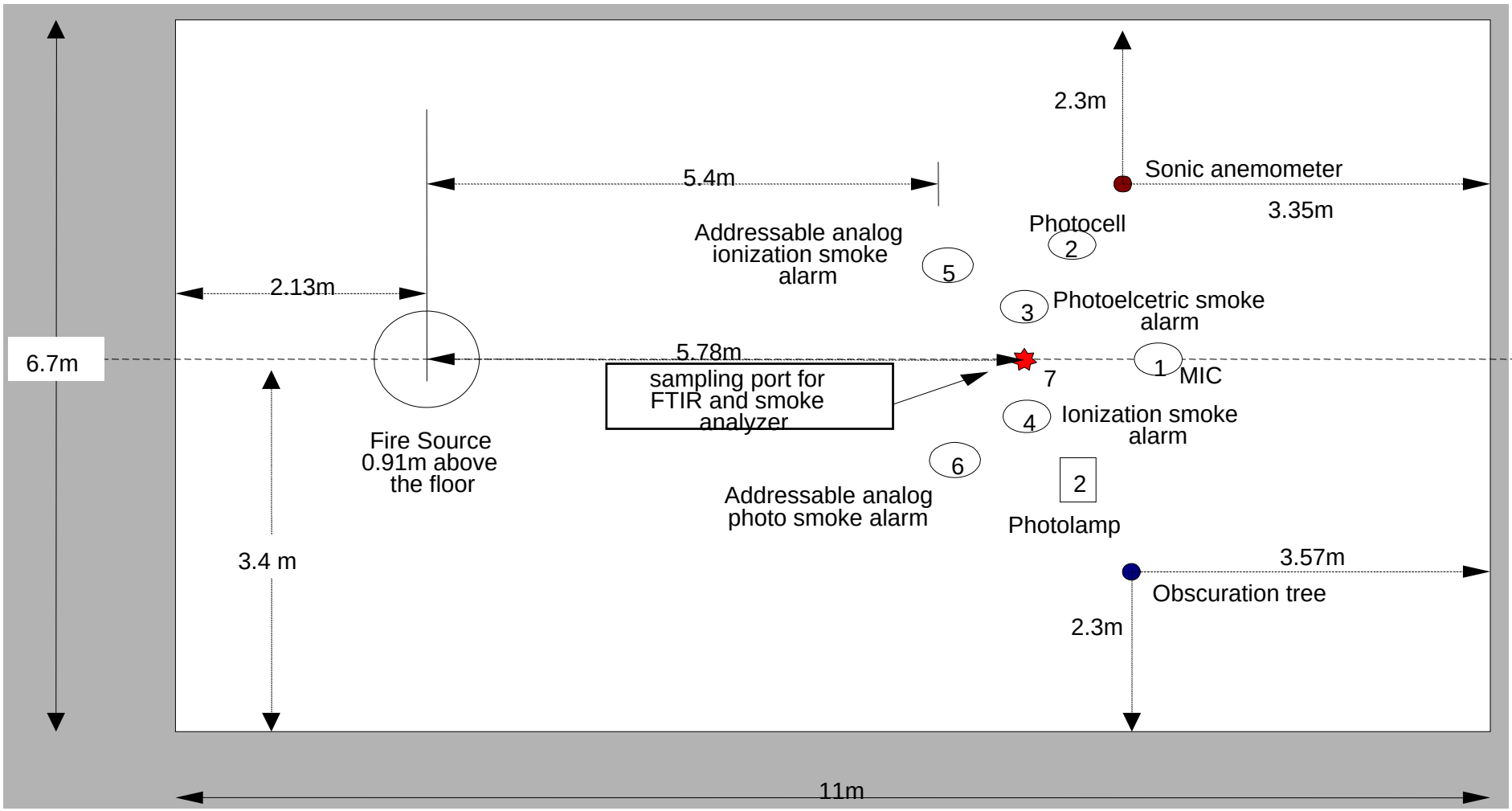


Smoke Characterization

Characterized UL 217 Section 44 fire test samples and the additional test samples and fire scenarios as follows:

- **smoke particle size and count distribution**
- **gas effluent composition**
- **analog addressable smoke alarm signals**
- **standard light obscuration beam and MIC signals**
- **standard photoelectric and ionization alarm signals**
- **ceiling air velocity**
- **ceiling air temperature**

Test Room Description



Key Findings - Gas Analysis and Smoke Characterization Measurement

<u>Smoke Gas Effluent Composition</u> - Gas effluent analysis showed the <u>dominant</u> gas components were water vapor, carbon dioxide and carbon monoxide.

Water	CO_2	CO
SO_2	NO_2	Methane
Ammonia	Phenol	SiF_4
Formaldehyde	HCN	Propane
HCl	HF	Ethylene
Acrylonitrile	Styrene	

Key Findings - UL 217/UL 268 Fire Test Room Tests

<u>Smoke Particle Size and Count Distribution</u> - The tests provided smoke particle size and count distribution data in conjunction with traditional obscuration and Measuring Ionization Chamber data. PU foams in the flaming mode produced the smallest particle sizes of all materials tested.

Key Findings - UL 217/UL 268 Fire Test Room Tests

Flaming Tests	Mean Diameter at:	
	0.5 %/ft	10 %/ft
Douglas fir	0.13	0.17
Newspaper	0.17	0.18
Heptane/Toluene	0.19	0.30
Coffee maker	0.17	0.18
PU foam	0.08	NA
PU foam in Cotton/Poly	0.09	NA
Nylon carpet	0.10	NA

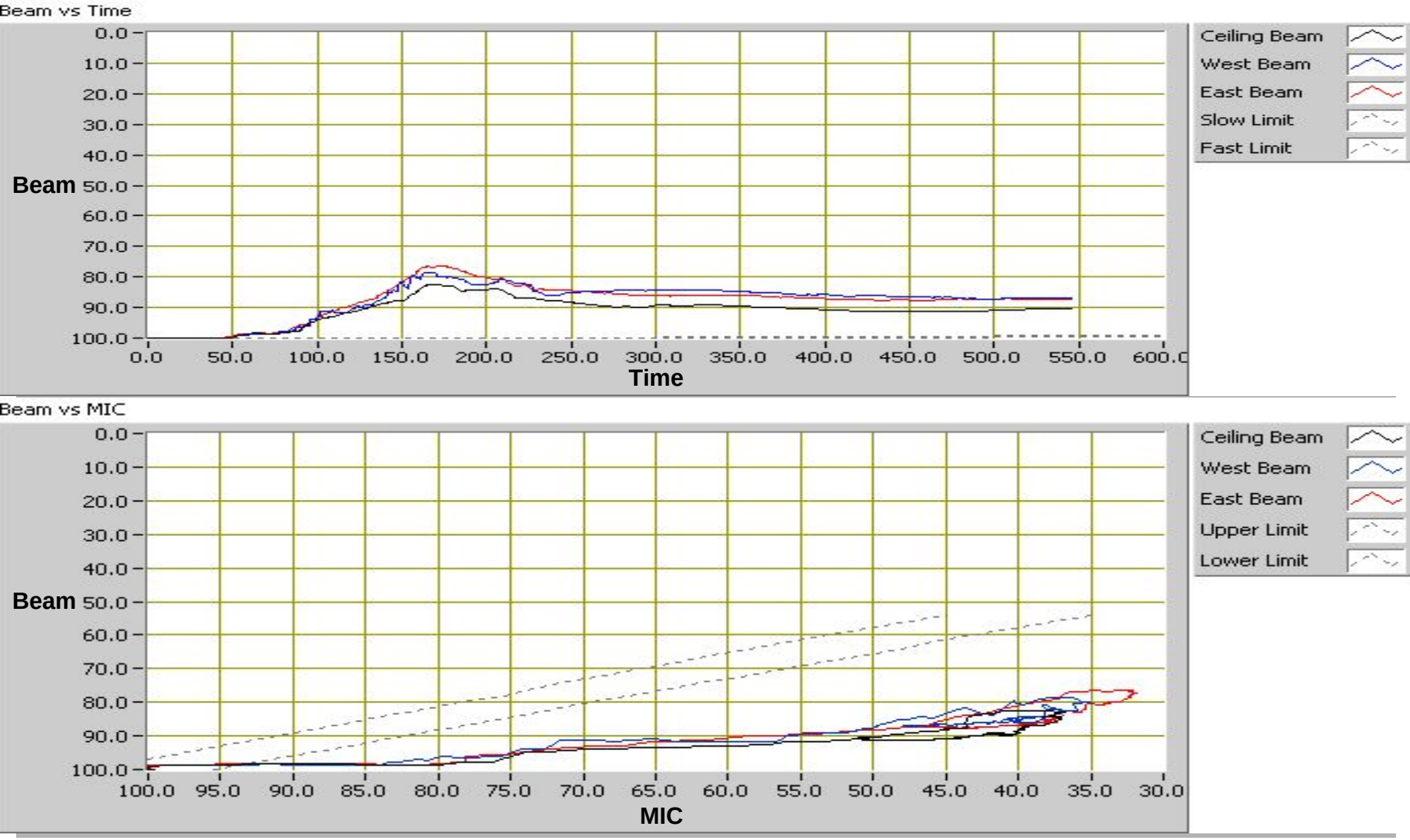
Key Findings - UL 217/UL 268 Fire Test Room Tests

Combustion Effects - Changes in the combustion mode (flaming versus non-flaming) resulted in different smoke particle size and count distributions that influenced the response of photoelectric and ionization smoke alarms. The particle size distribution for the non-flaming fires yielded larger mean smoke particle diameter than the flaming mode fires. The ionization alarm responded quicker to flaming fires; the photoelectric responded quicker to non-flaming fires.

Key Findings - UL 217/UL 268 Fire Test Room Tests

Smoke Alarm Response to Flaming Fires - In all but one flaming test the ion alarm activated first. Both alarm types activated within the 4 minute time limit specified in UL 217 for the three UL 217 flaming test targets (Douglas fir, heptane/toluene mixture, and newspaper). In one of two flaming tests involving PU foam with cotton/poly fabric the photoelectric smoke alarm did not activate, however the ionization alarm did activate in both tests. In a flaming PU foam with cotton/poly fabric test using a smaller sample size neither alarm type activated. It should be noted that the maximum obscuration in these PU foam tests was less than for Douglas fir, heptane/toluene mixture, and newspaper test samples.

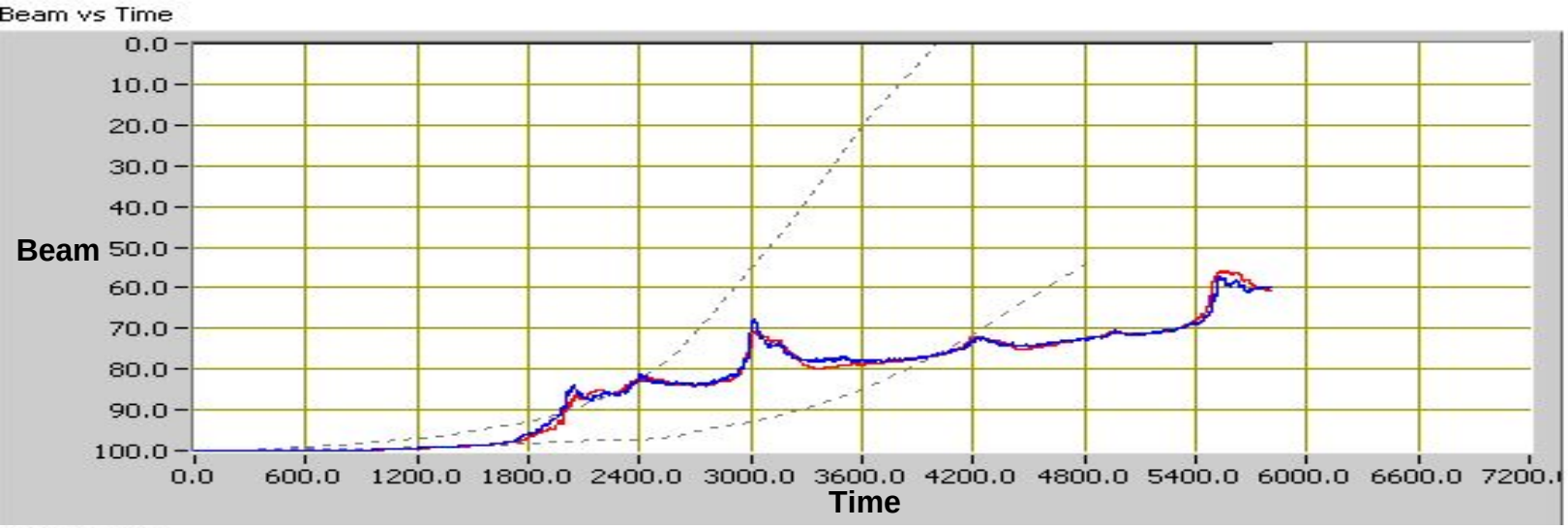
Flaming PU Foam

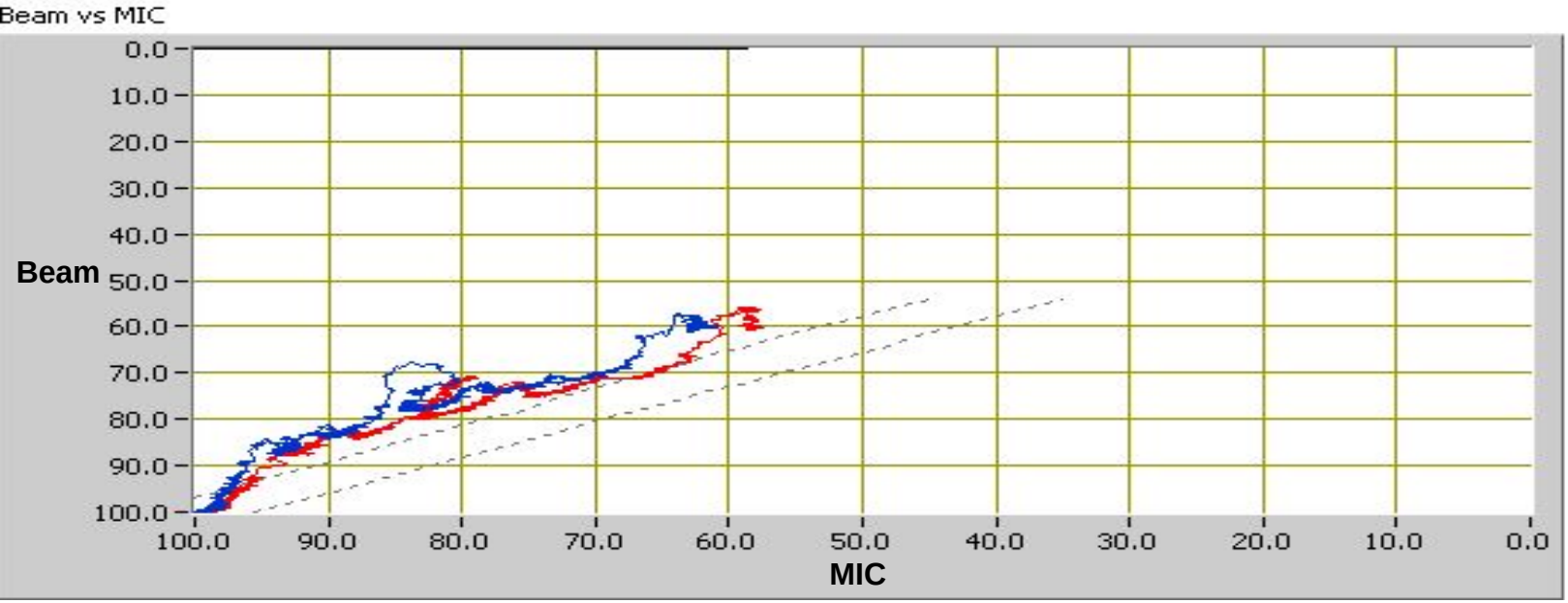


Key Findings - UL 217/UL 268 Fire Test Room Tests

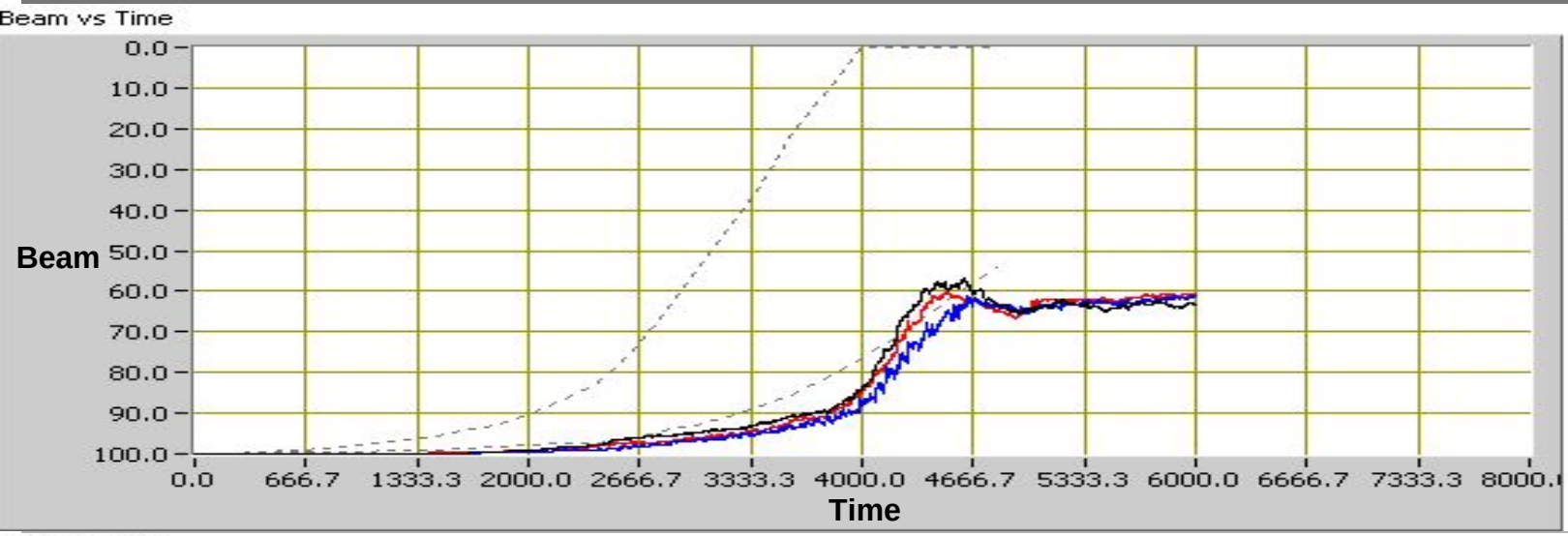
Smoke Alarm Response to Non-Flaming Fires – The photoelectric alarm activated first in the non-flaming tests with the exception of the higher energy bread/toaster test in which the ion alarm activated first. The UL 217 smoldering Ponderosa pine test triggered both the ionization and photoelectric smoke alarms. For many of the other materials, the ionization smoke alarm did not trigger. In each of these cases, the obscuration value was less than the 10 %/ft limit specified in UL 217. It was also found that there was settling of the smoke particles in the test room over time. Measurements from several non-flaming tests showed that the obscuration values at the ceiling dropped over time, and the maximum obscuration values were observed at the 2 feet measurement location below the ceiling.

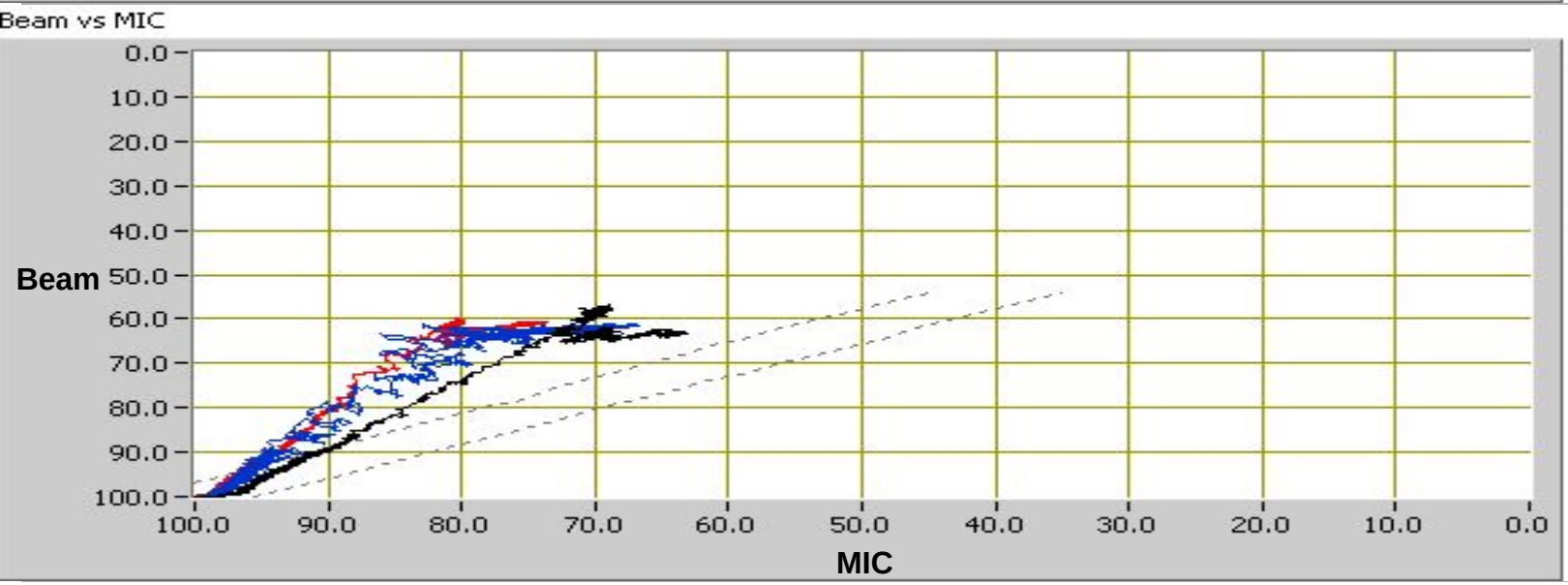
Smoldering Polyurethane Foam





Smoldering Polyurethane Foam 5X5 10 Cotton Cover





Key Findings - UL 217/UL 268 Fire Test Room Tests

Flaming Tests	Alarm Trigger Time (s)	
	Ion	Photo
Douglas fir	142	172
Newspaper	133	150
Heptane/Toluene	35	70
Coffee maker	181	386
PU foam	68	DNT
PU foam in Cotton/Poly	104	171
Nylon carpet	157	272

Key Findings - UL 217/UL 268 Fire Test Room Tests

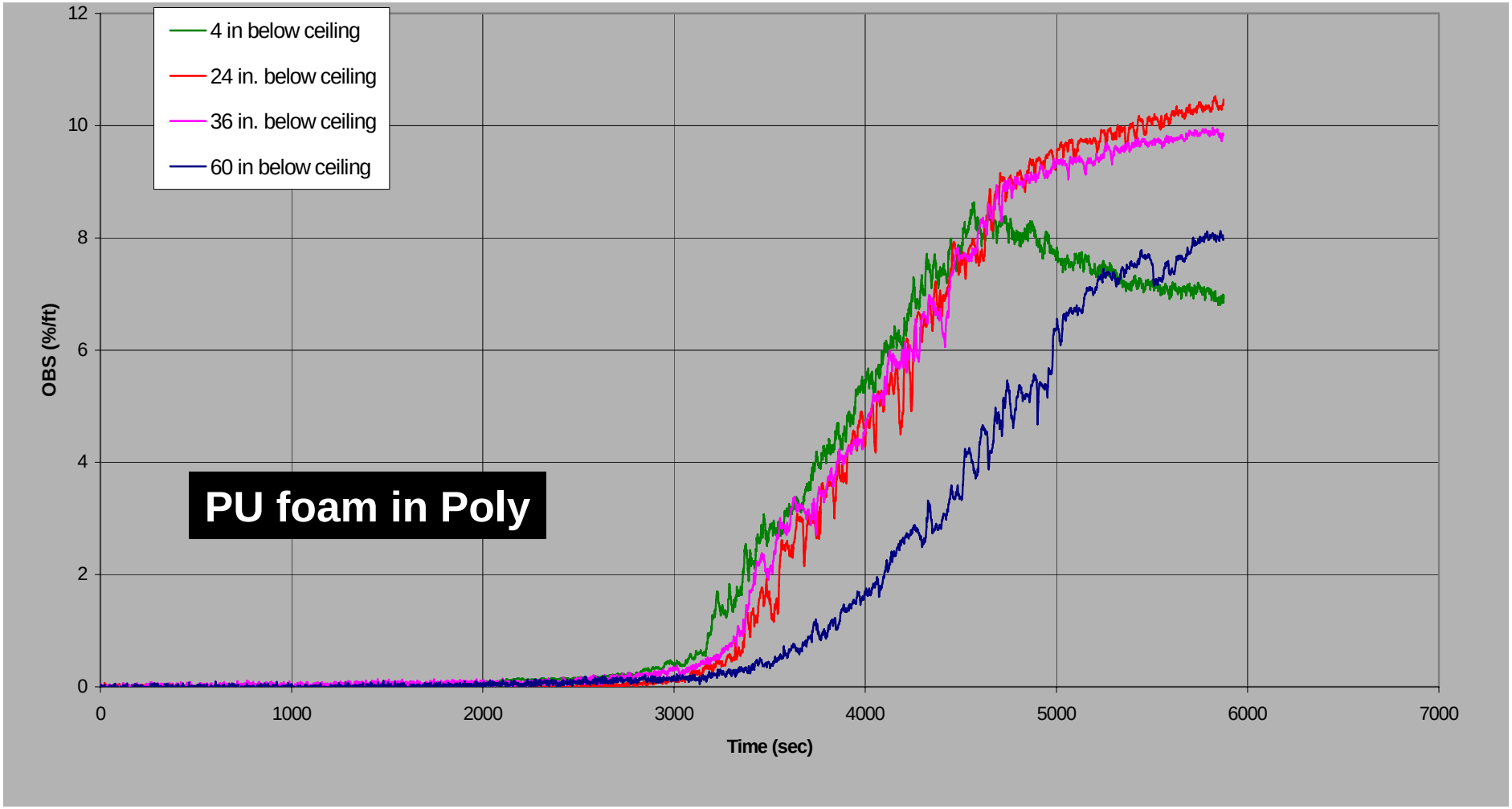
Non-Flaming Tests	Alarm Trigger Time (s)	
	Ion	Photo
Ponderosa pine	3378	3304
Polyisocyanurate	DNT	DNT
PU foam	5610	3032
PU foam in Cotton	DNT	3870
PU foam in Poly	DNT	4741
Nylon carpet	DNT	5727
Polystyrene	DNT	5546
Bread	*323*	*394*

Key Findings - UL 217/UL 268 Fire Test Room Tests

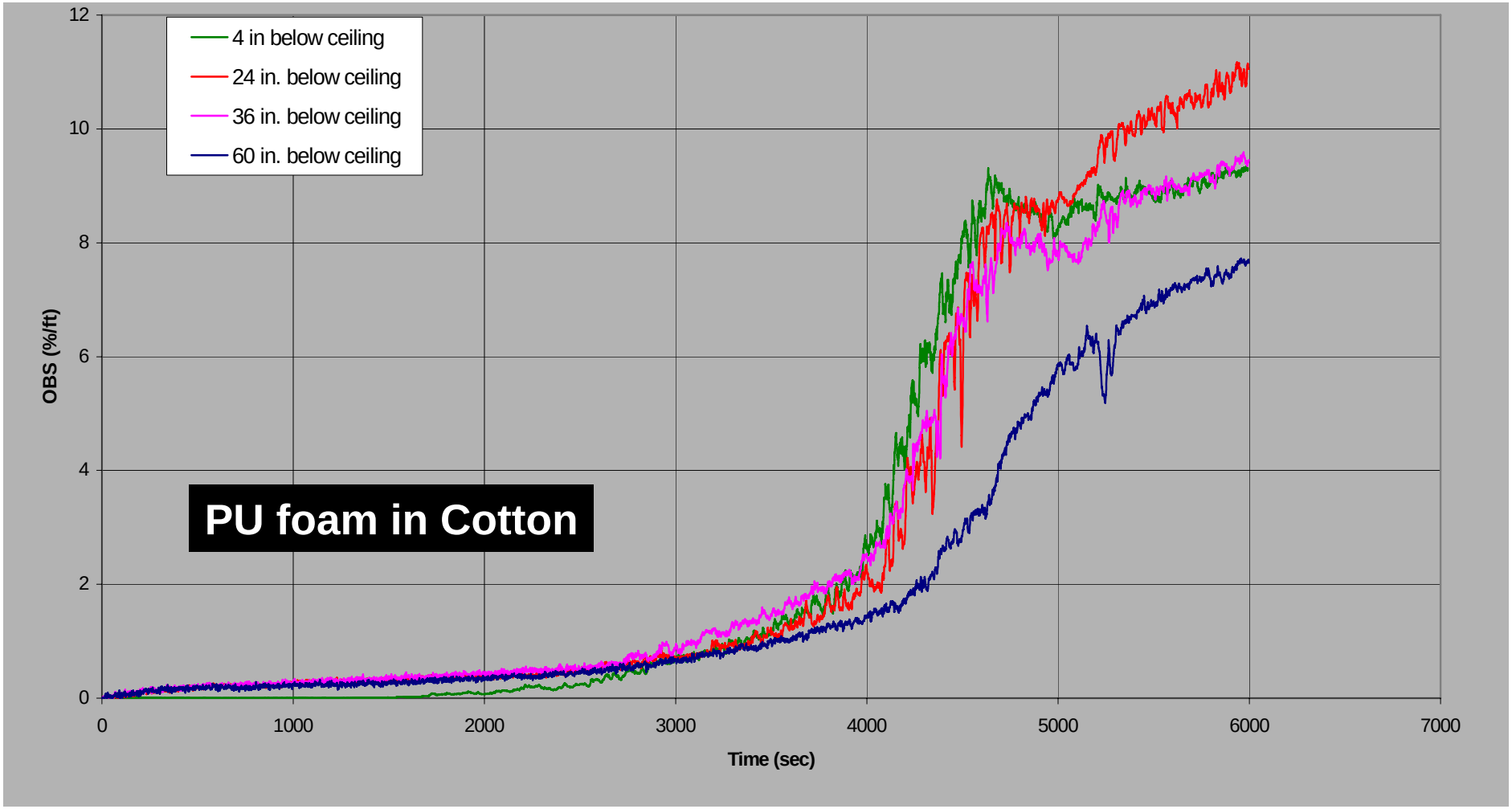
<u>Smoke Stratification</u> - Non-flaming fires result in changes in the smoke build up over time, such that stratification of smoke below the ceiling occurs. This time-dependent phenomenon results in less obscuration at the ceiling than below the ceiling. This caused both detection technologies to drift out of alarm.

Key Findings - Fire Test Room

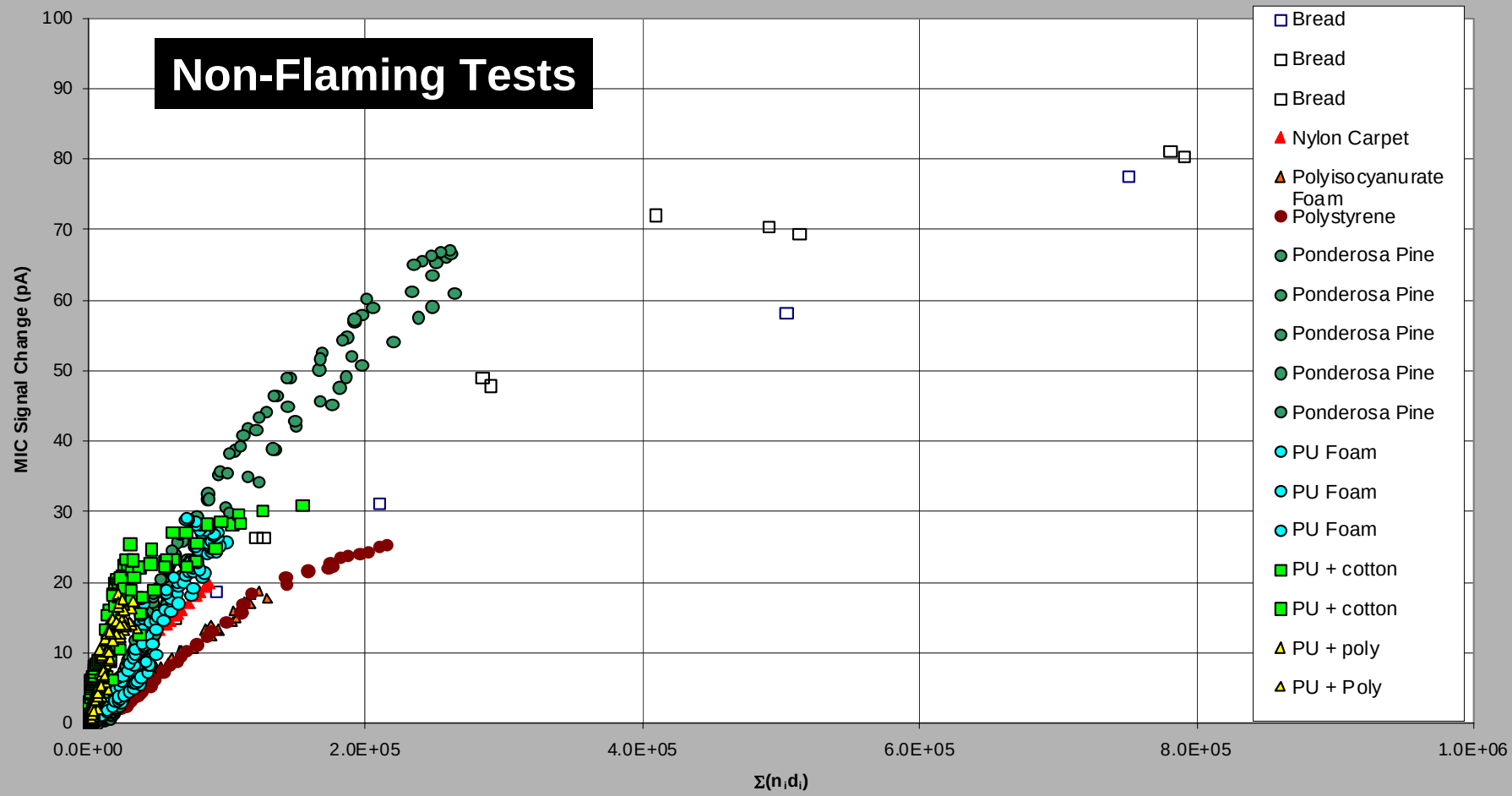
Key Findings - Stratification Fire Test Room Test 1



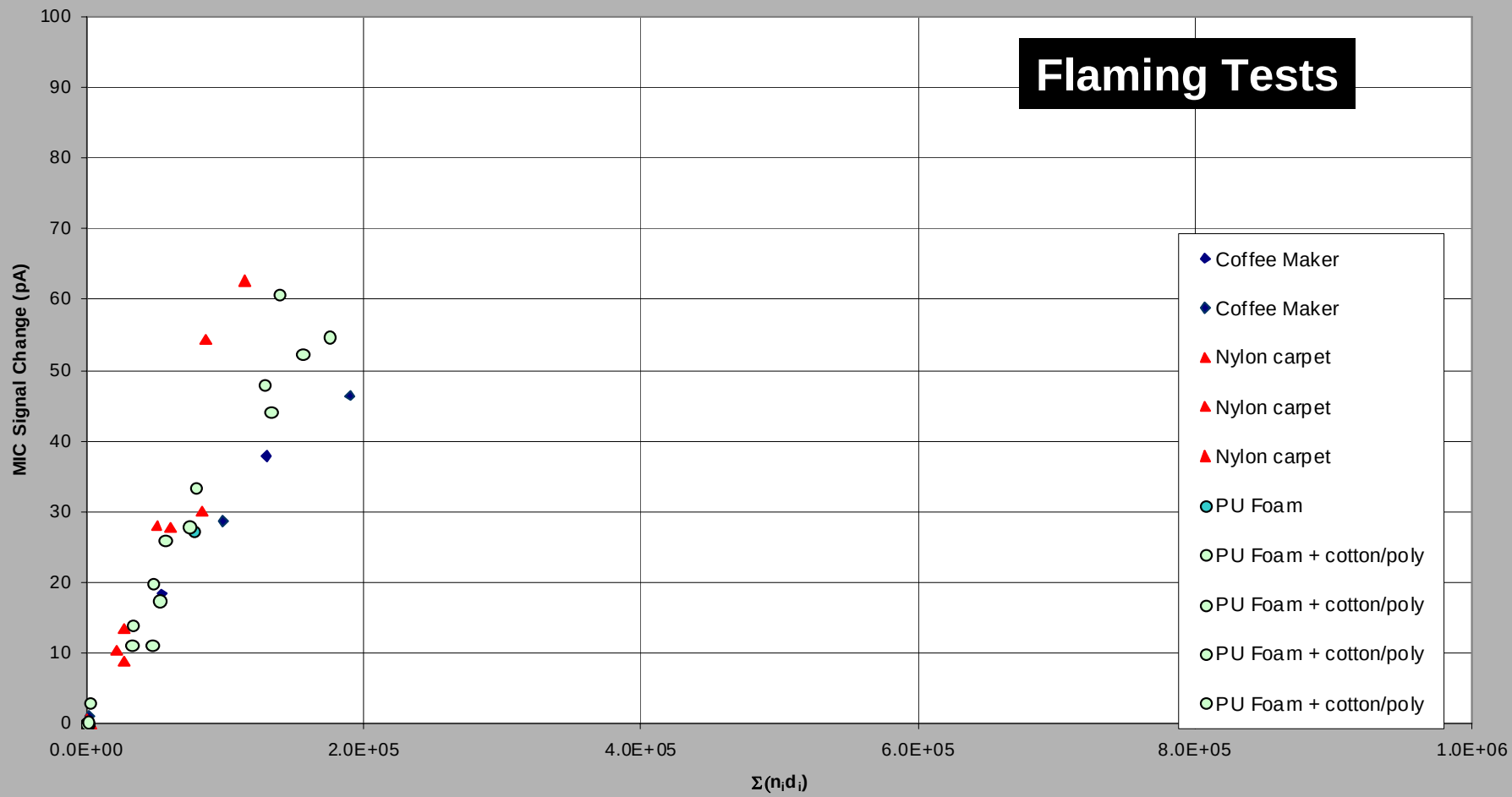
Key Findings – Stratification Fire Test Room Test 2



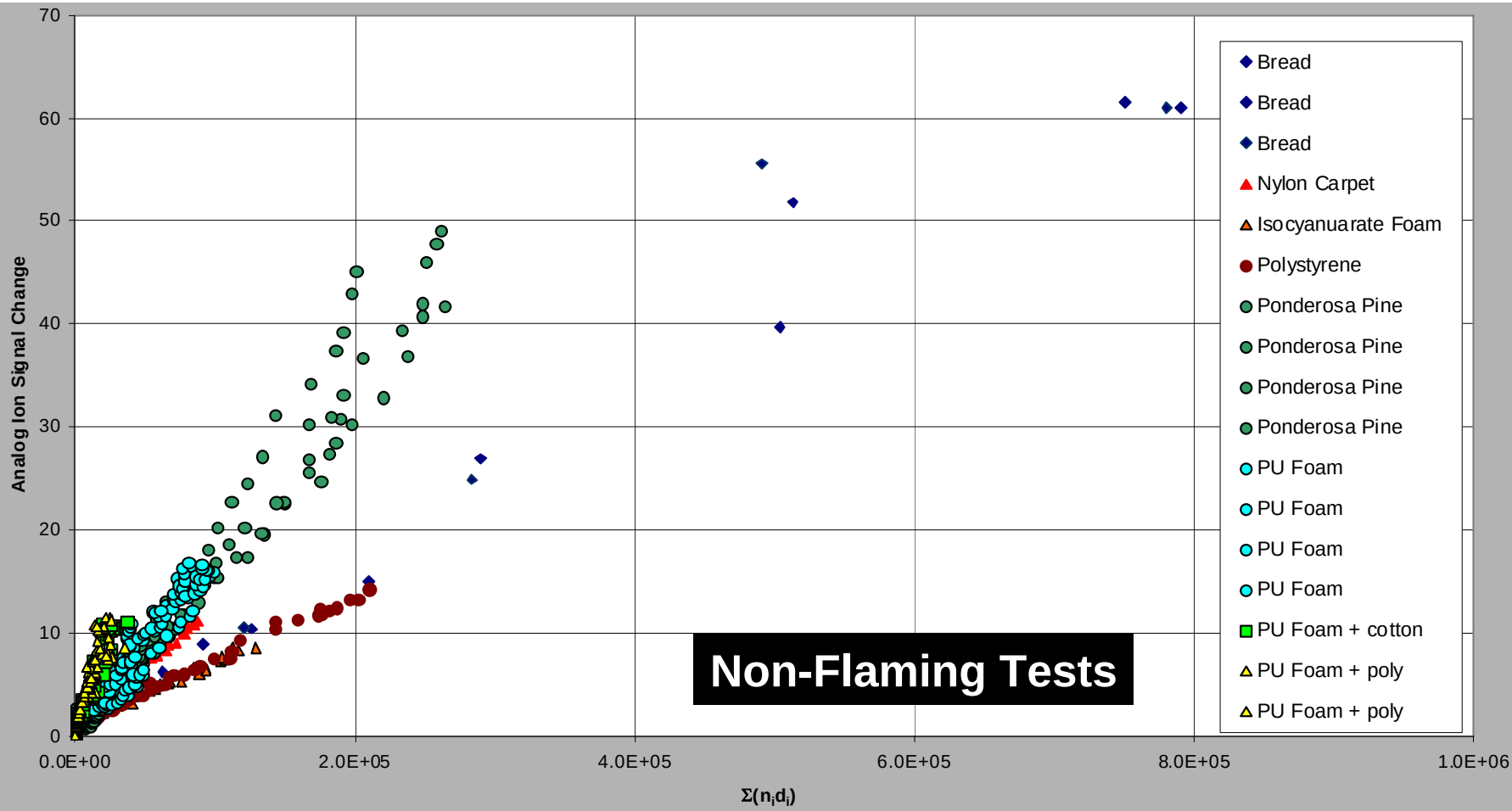
Key Findings - Fire Test Room MIC -- Non-Flaming



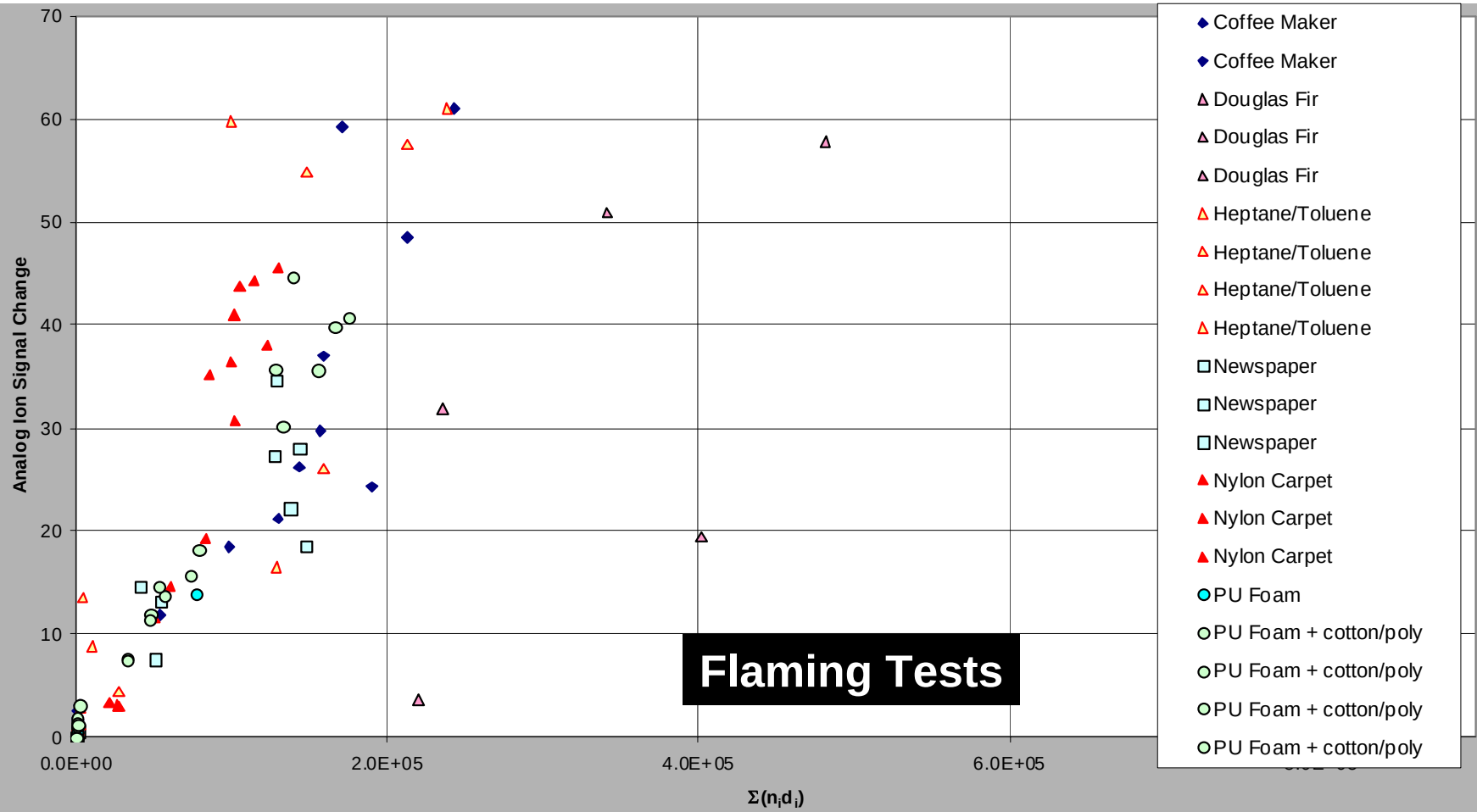
Key Findings - Fire Test Room MIC -- Flaming



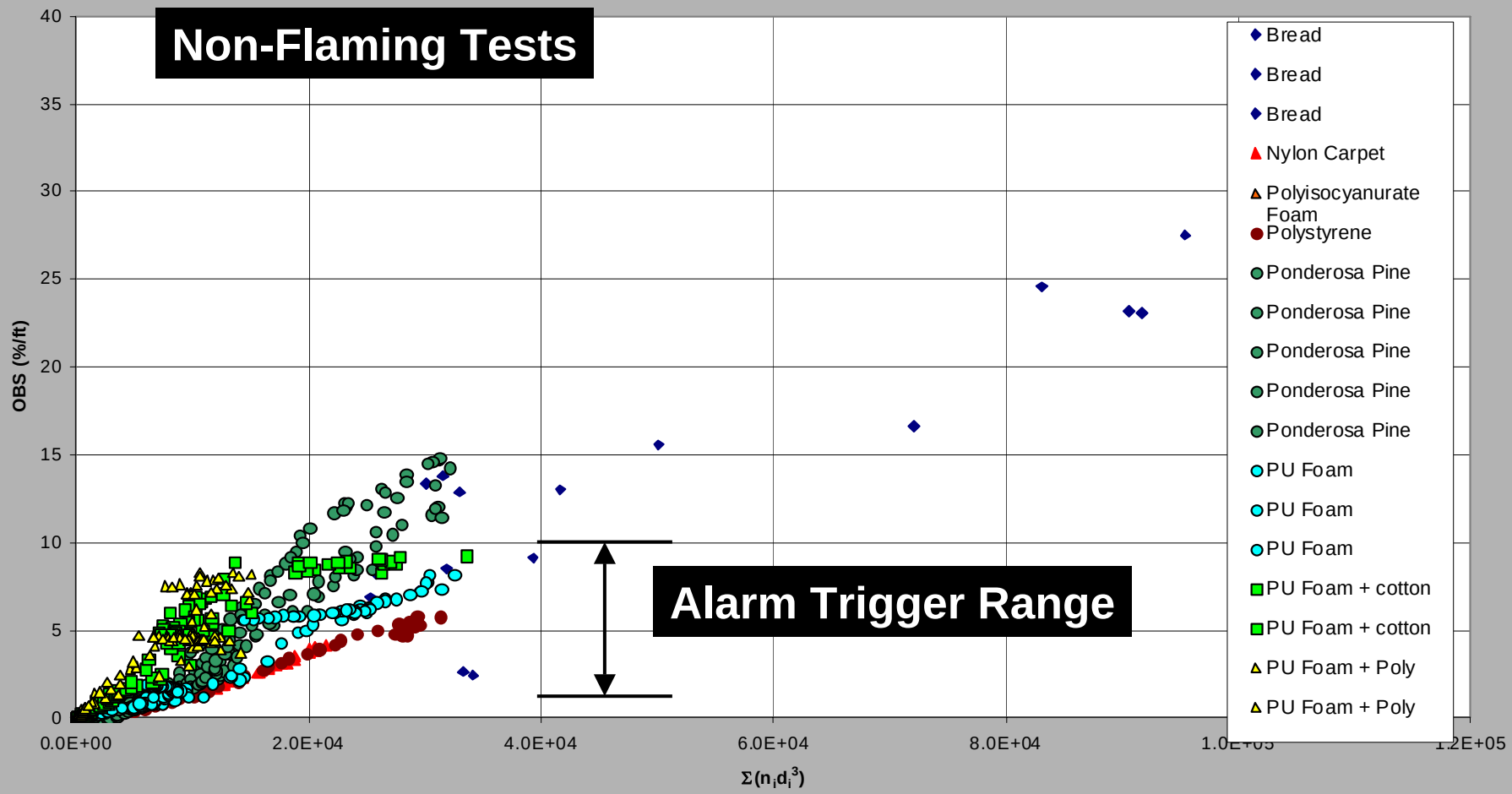
Key Findings – Ion Analog Signal Non-Flaming Fire Tests



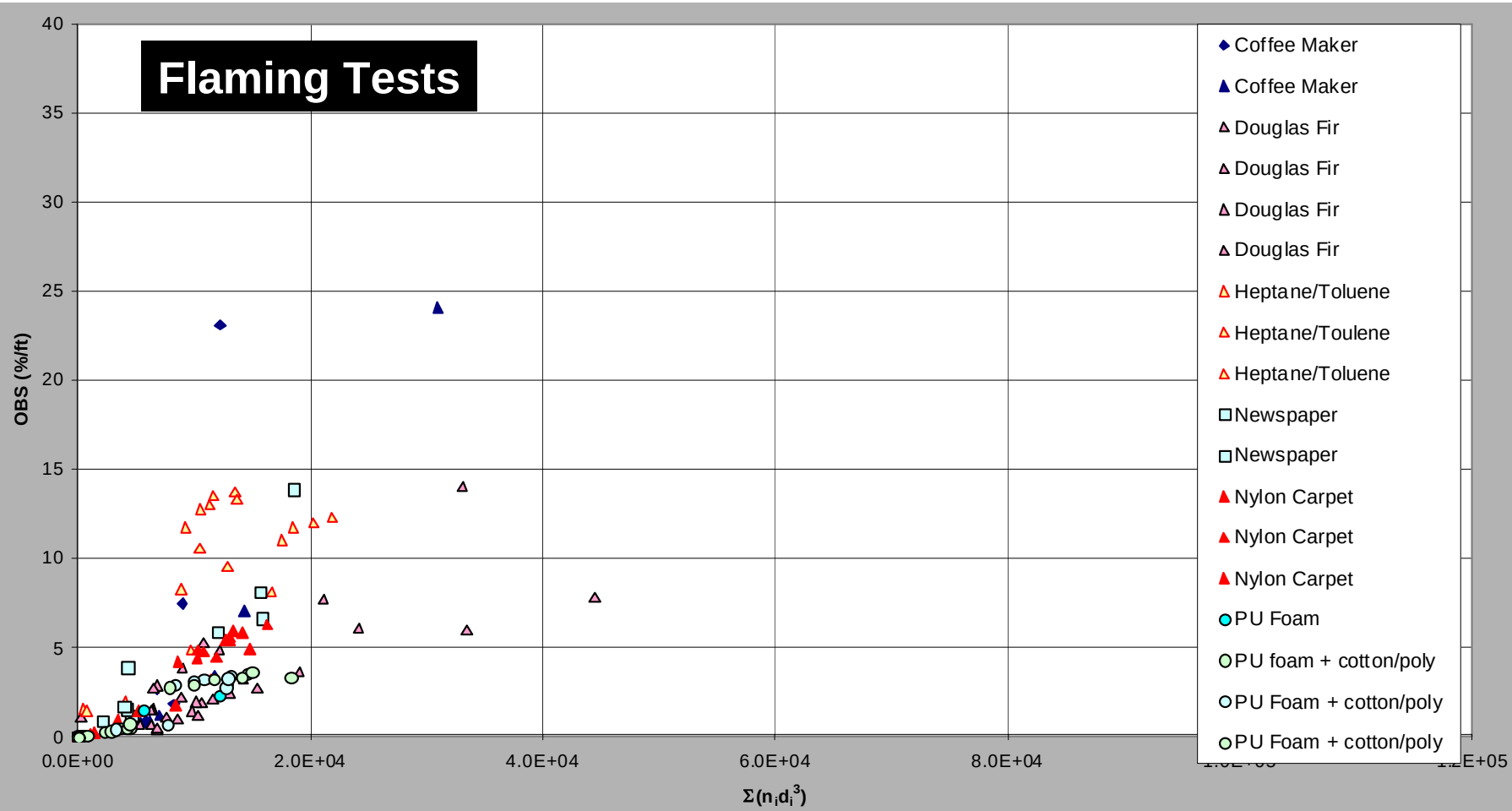
Key Findings – Ion Analog Signal Flaming Fire Tests



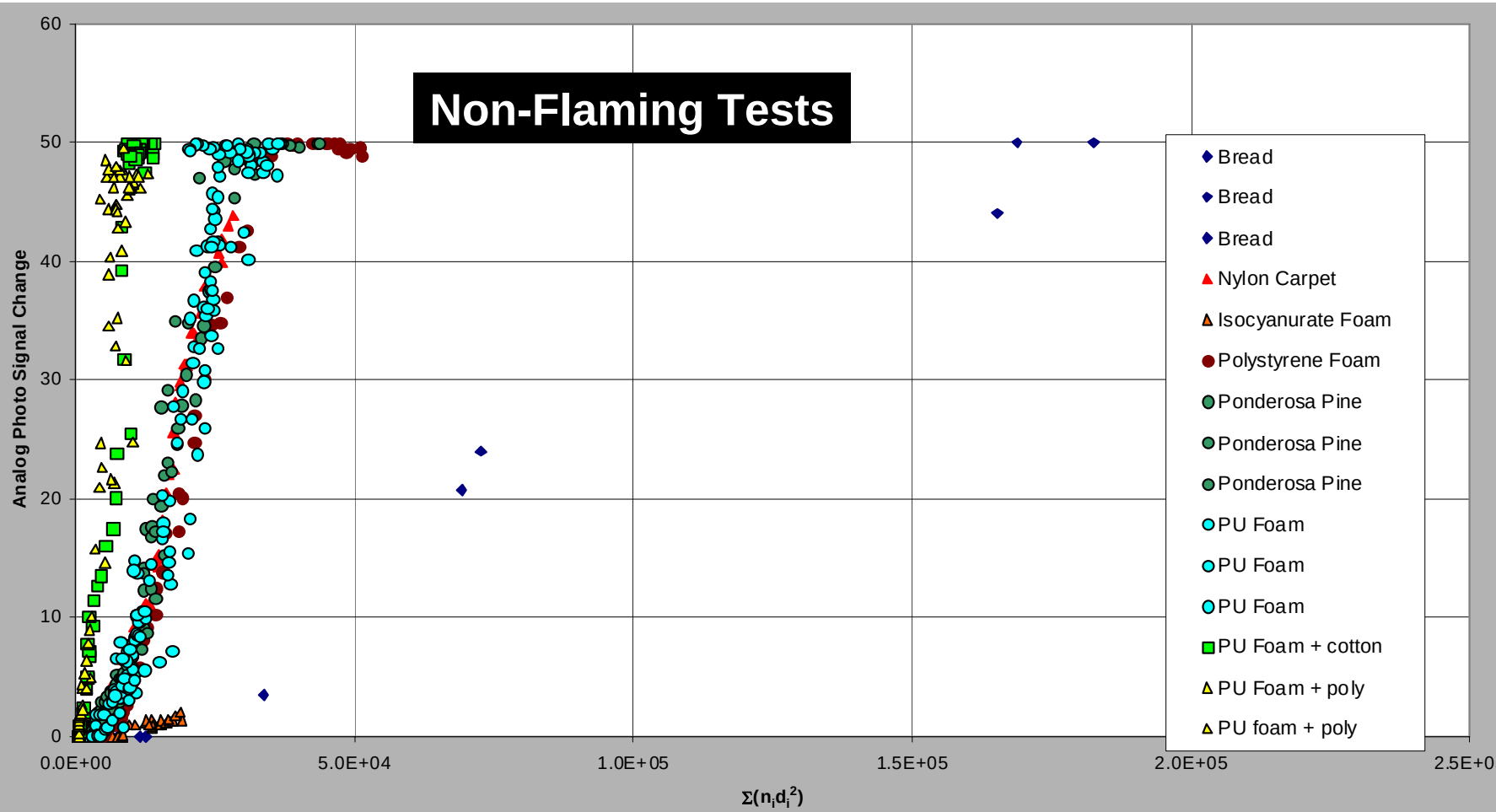
Key Findings – Fire Test Room Beam Non-Flaming Fire Tests



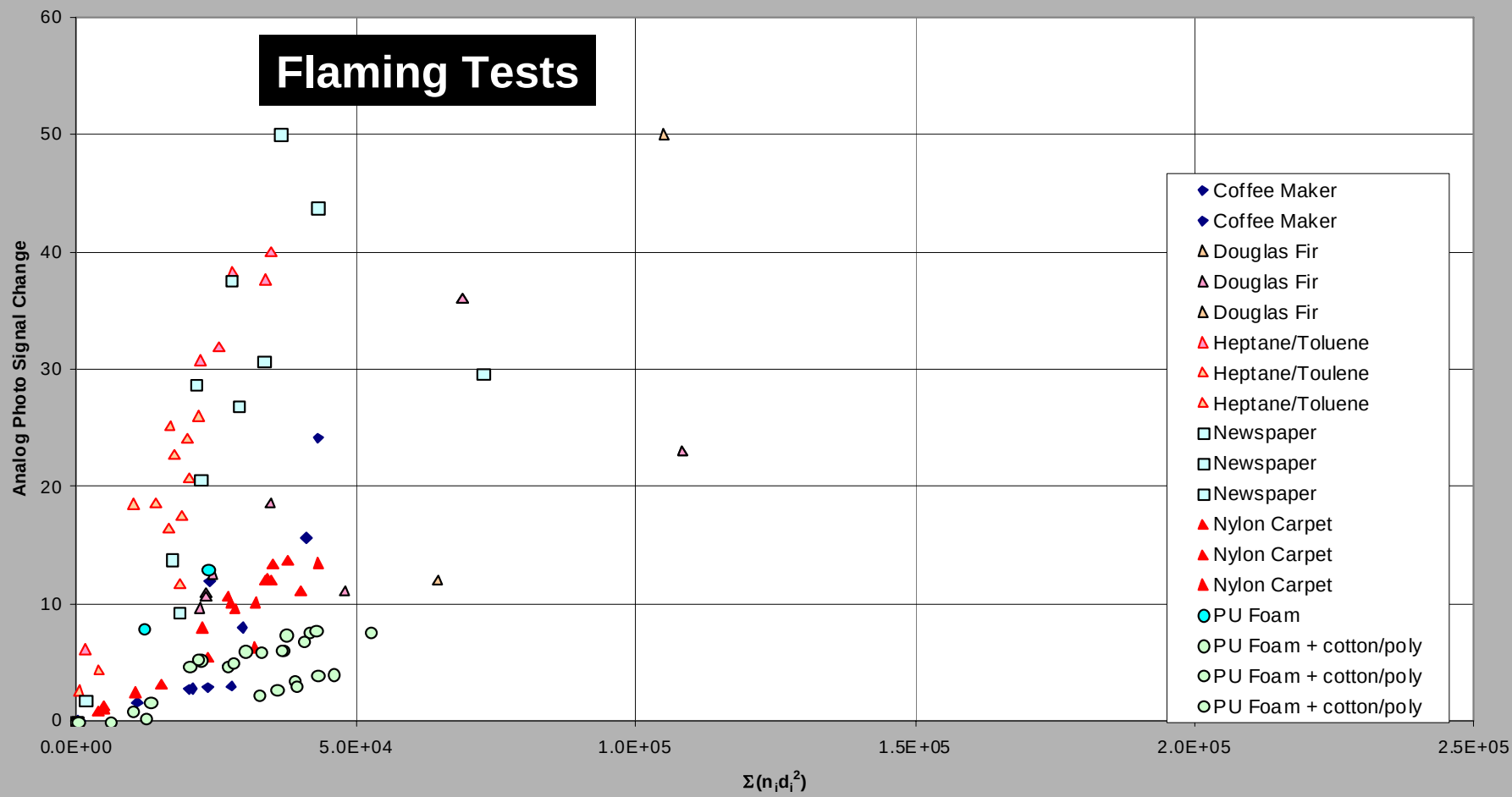
Key Findings – Fire Test Room Beam Flaming Fire Tests



Key Findings – Photo Analog Signal Non-Flaming Fire Tests



Key Findings – Photo Analog Signal Flaming Fire Tests



Summary

Stratification

Very low energy, or remote fires

--- To minimize the impact of stratification, alarms should be installed as described in NFPA 72 Chapter 11.

Nonspecific Fire

Install as described in NFPA 72 Chapter 11, and there are several complex variables to consider when designing a residential smoke alarm system, such as; fire type (smoldering, flaming), material chemistry involved in the fire, and color of smoke. Consideration should be given to specify the use of smoke alarms that display the performance characteristics of combination ionization and photoelectric alarms in order to maximize the responsiveness of the alarm to this broad range of variables resulting from nonspecific fires.

Polyurethane Test Fires

UL is currently developing standardized flaming and smoldering smoke PU foam tests

Fire Tests: Smoke Characterization of Flaming and Smoldering Fires

Report Availability

Free download at: www.nfpa.org/

Research and Reports/

Fire Protection Research Foundation/

Reports/

Smoke Characterization Project Technical Report

Paul E. Patty, P.E. **tel: 1-847-664-2752** **paul.e.patty@us.ul.com**